

FERMION GENERATIONS FROM THE HIGGS SECTOR

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Abstract

The generation structure in the quark and lepton spectrum is explained as originating from the excitation spectrum S_n of $SU(2)_W$ doublet scalar fields, whose ground state S_1 is the Standard Model Higgs field. There is only one basic family of $SU(2)_W$ doublet left-handed fermions, ν_L, e_L, u_L, d_L , whose bound states with S_n manifest themselves as the generations of left-handed quarks and leptons. Likewise, there is only one basic family of the right-handed fermions, ν_R, e_R, u_R, d_R , which combine with the gauge invariant scalar fields G_n to produce the right-handed quarks and leptons of the second and higher generations. There are only four Yukawa coupling constants, G_ν, G_e, G_u , and G_d and all quark and lepton masses are proportional to them. Suppression of flavor changing neutral currents (GIM mechanism) is automatic. ν_μ and ν_τ are expected to be massive.

I present a theory of the origin of fermion generations in which there is only one fundamental quark/lepton family, while the second and higher ones are a consequence of an excitation spectrum in the scalar sector. The basic family of chiral fermions consists of

$$\ell_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \nu_R, e_R, u_R, d_R$$

with the usual $SU(2)_W \otimes U(1)_Y$ transformation properties. In addition to the fermions, there is a composite bosonic field S whose lowest energy states are the $SU(2)_W$ doublet scalars

$$S_1 = \begin{pmatrix} S_1^+ \\ S_1^0 \end{pmatrix}, S_2 = \begin{pmatrix} S_2^+ \\ S_2^0 \end{pmatrix}, S_3 = \begin{pmatrix} S_3^+ \\ S_3^0 \end{pmatrix} \dots$$

We shall assume that there are at least three scalar states below the lowest $J = 1$ state. The ground state S_1 is the familiar Higgs field which develops a vacuum expectation value. S_2, S_3 , etc. are its radial excitations labeled by the “generation number.” Orthogonality of the states $S_1, S_2, S_3 \dots$ implies that for $n \geq 2$, S_n has zero vacuum expectation value and zero Yukawa couplings. It also requires that the effective quartic couplings of these states respect the generation number, at least at energies much lower than their mass scale. Under this assumption the effective potential can only be a function of $S_i^\dagger S_i$ and $(S_i^\dagger S_j)(S_j^\dagger S_i)$ and the low energy effective theory possesses a global $SU(2)$ symmetry, the isospin.

Note that this scheme has nothing to do with Technicolor which is a QCD-like theory invented to solve the fine-tuning problem and does not address the fermion generation problem. The S -field envisaged here explains the existence of fermion generations as its radial excitation states. For this purpose it is not necessary to assume QCD-like structure for the S -field – or even that it is based on a new interaction at all.

Gauge invariant scalars

The gauge invariant scalar fields are obtained in the $S_i^\dagger S_j$ (neutral) and $\bar{S}_i^\dagger S_j$ (charged) channels, where $\bar{S} = i\tau_2 S^*$. The fields involving the ground state S_1 are of particular importance, since S_1 is the only Higgs field in the theory (i.e. the field which has negative mass squared in the Lagrangian) and plays a special role in producing the W 's, the Z , and the left-handed fermions of the first generation. The only gauge invariant scalar involving only S_1 is $h^0 = \sqrt{2}(S_1^0 - \langle S_1^0 \rangle)$, the physical Higgs field. For every $n \geq 2$ we have a positive scalar $G_n^+ = \bar{S}_1^\dagger S_n$ and a neutral scalar $G_n^0 = S_1^\dagger S_n$, both of which are labeled by n and thus come in generations. As we shall see, the G_n fields give their generation number to the right-handed fermions and thus are responsible for the generation structure in the right-handed sector.

The quarks and leptons

The left-handed fermions of the n -th generation, $\nu_{nL}, e_{nL}, u_{nL}, d_{nL}$, are composed of the fundamental left-handed fermions ℓ_L and q_L and the n -th generation S field, S_n :

$$\begin{aligned}\nu_{nL} &= \bar{S}_n^\dagger \ell_L \\ e_{nL} &= S_n^\dagger \ell_L \\ u_{nL} &= \bar{S}_n^\dagger q_L \\ d_{nL} &= S_n^\dagger q_L.\end{aligned}\tag{1}$$

The right-handed fermions of the n -th generation are composed of the fundamental right-handed fermions ν_R, e_R, u_R, d_R , and the G_n fields from which they get their generation label:

$$\begin{aligned}\nu_{nR} &= G_n^+ e_R + G_n^0 \nu_R \\ e_{nR} &= G_n^{0*} e_R + G_n^- \nu_R \\ u_{nR} &= G_n^+ d_R + G_n^0 u_R \\ d_{nR} &= G_n^{0*} d_R + G_n^- u_R.\end{aligned}\tag{2}$$

The left- and the right-handed fermions of the first generation meet at the usual Yukawa vertices, Fig. 1(a), while those of the second and higher generations meet at the vertices shown in Fig. 1(b). The four Yukawa coupling constants, G_ν, G_e, G_u , and G_d are the only chiral symmetry breaking parameters in the theory and thus all fermion masses are proportional to them. In the limit in which these coupling constants go to zero all fermions are massless, irrespective of how massive their scalar constituents S_i may be. Note, however, that the quark (lepton) masses of the second and higher generations get contributions from

both G_u and G_d (G_ν and G_e),

$$m_c = Am_u + Bm_d$$

$$m_s = Cm_u + Dm_d$$

and analogous in the lepton sector. In particular, this implies that the muon and tau neutrinos are massive even if $G_\nu = 0$, due to the contributions from the electron to those two neutrinos.

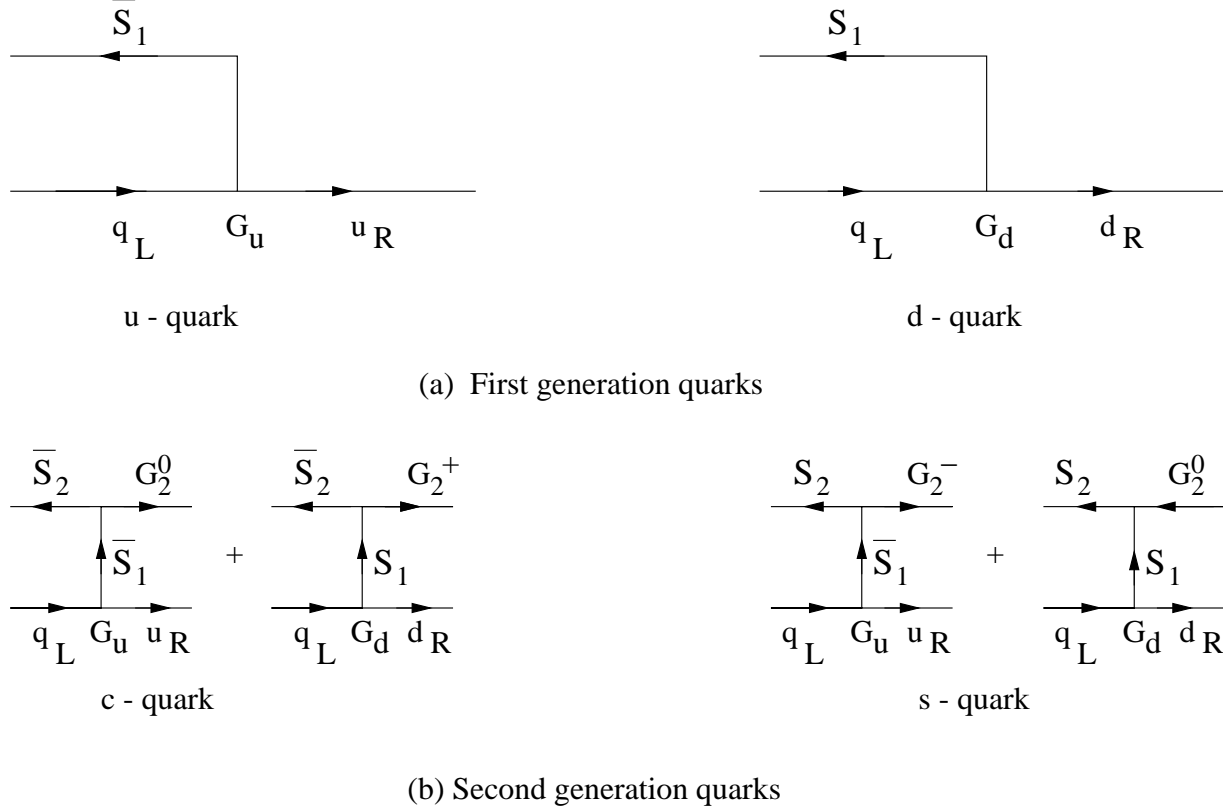


Fig. 1 The mass term for the first (a) and the second (b) generation quarks.

The W and Z couplings and the mixing angles

In the Standard Model the W and Z bosons couple to $\bar{S}_1^\dagger(A_\mu - \frac{i}{g}\partial_\mu)S_1$ and $S_1^\dagger(A_\mu - \frac{i}{g}\partial_\mu)S_1$ where A_μ denotes the $SU(2)_W$ gauge field. Here I postulate similar couplings of the W and Z bosons to the excited states, i.e. to $\bar{S}_i^\dagger(A_\mu - \frac{i}{g}\partial_\mu)S_j$ and $S_i^\dagger(A_\mu - \frac{i}{g}\partial_\mu)S_j$. This makes it possible to couple the W 's and the Z to the quarks and leptons. However, the quark and lepton mass eigenstates are the bound states, Eq. (1). The W coupling to the mass eigenstates involves the mixing matrix elements V_{ij} , equal to the overlap integral of the quark wave functions,

$$V_{ij} = \langle u_{iL} | d_{jL} \rangle = \langle \bar{S}_i^\dagger q_L | S_j^\dagger q_L \rangle .$$

As shown in Ref. 1, orthogonality and completeness of the quark wave functions ensure the unitarity of the mixing matrix V and thus the absence of flavor changing neutral currents (GIM mechanism). Alternatively, we may directly show that the off-diagonal couplings of the Z involving S fields of different generations are zero because of orthogonality of the S_n states. Higher order corrections, of course, do not respect the orthogonality and introduce flavor changing neutral currents.

Conclusions

The proposed theory of quark and lepton generations predicts that, except for the first one, each quark and lepton generation is accompanied by a pair of scalar fields, G_n^+ and G_n^0 . Thus both the fermions and the scalars come in generations which originate in the spectrum of the S -field. Ultimately the model should predict the number of quark/lepton generations and their masses. Even in the absence of these predictions, we may notice that the fermion generations predicted here differ in two important aspects from higher fermion generations which would obey the rules of the present Standard Model. First, although they may be heavy, they do not involve large Yukawa couplings and thus do not lead to new strong interactions among quarks/leptons. Heavy fermions are obtained as bound states and not as a result of large Yukawa couplings. Second, even if the number of quark generations turns out to be large, the asymptotic freedom properties of QCD may not be affected, since there are only two basic quark flavors, u and d , all other quark flavors being bound states of these two.

References

1. V. Visnjic, *Phys. Rev.* **D25** (1982) 248.